(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 718 496 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
26.06.1996 Bulletin 1996/26

(51) Int Cl.[6]: **F04B 49/06**

(21) Application number: **95308558.6**

(22) Date of filing: **28.11.1995**

(84) Designated Contracting States:
DE FR GB

(30) Priority: **19.12.1994 US 358506**

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(54) **A variable assist electro-hydraulic system**

(57) An electro-hydraulic system has at least one hydraulic load receiving pressurized fluid from a pump energized by an electric motor; the fluid flow/pressure characteristics are determined by motor speed, which is set by an electronic controller responsive to a motor/pump parameter sensed within the controller itself. No system parameter external to the electronic controller is required to be sensed to maintain system operation.

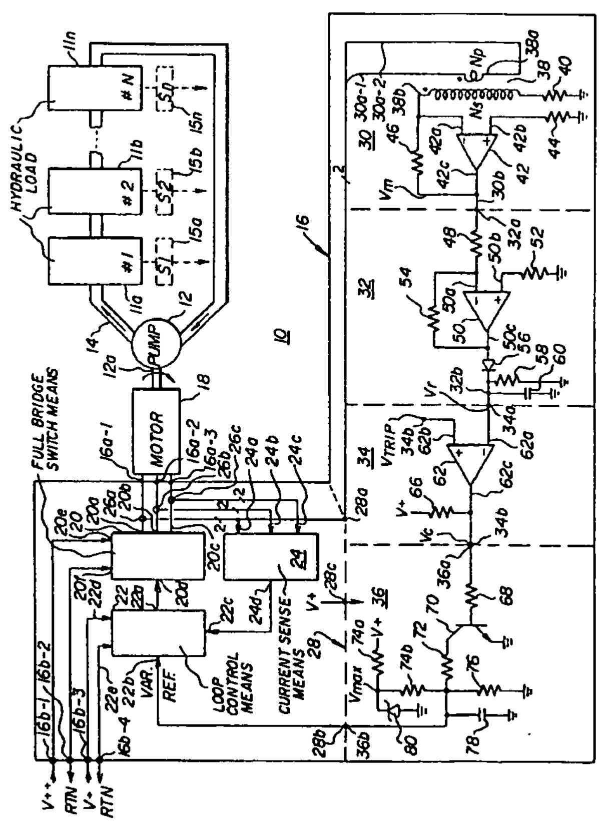

FIG. 1

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Description

The present invention relates to electro-hydraulic systems and, more particularly, to a novel electro-hydraulic system in which pump pressure is determined by a variable motor speed responsive to hydraulic load effects upon a motor parameter internally sensed in the motor controller.

Background of the Invention

In a typical electro-hydraulic system, hydraulic fluid is provided under pressure by a pump driven by an electric motor; the motor is often run at a fixed RPM rate. In systems of this type there is no way to reduce flow rate if no fluid flow is required. As a result, some energy will be drawn from an electrical supply; that energy will not be used to provide any useful function. Additionally, electrical components will experience undue voltage and current levels and mechanical components will be required to operate at higher stress levels resulting in elevated temperatures and, ultimately, lower reliability.

One way to reduce the fixed losses in the above-mentioned system would be to separately sense a changing condition in the apparatus which acts, or is acted, upon by the hydraulic fluid and use the information to decrease or increase fluid flow. Implementing this type of control can reduce fixed losses by a factor of 10 or more and, in turn, improve the overall system function. The drawback is that use of a complicated control scheme is required and sometimes needs costly implementation requiring additional electrical and/or mechanical interfaces. The additional complexity may impose constraints on form and fit replaceability or become too costly to implement altogether.

It is desirable to utilize information inherent within the electronic control which, once extracted, offers all of the advantages of separate sensing without requiring any external sensing elements or additional electrical or mechanical interfaces. Fixed energy losses should be reduced and lower temperatures might be achieved with only minimal extra circuitry added to the electronic control. More specifically, we desire to improve the reliability and life of electro-hydraulic pump systems by reducing the fixed energy losses incurred by electro-hydraulic pump systems, while providing motor speed and hydraulic fluid flow rate variability without external sensing devices or interfaces.

Brief Summary of the Invention

In accordance with the present invention, an electro-hydraulic system has at least one hydraulic load receiving pressurized fluid from a pump energized by an electric motor; the fluid flow/pressure characteristics are determined by motor speed, which is set by an electronic controller responsive to a motor/pump parameter sensed within the controller itself. No system parameter external to the electronic controller is required to be sensed to maintain system operation.

In one presently preferred embodiment, the sensed parameter is motor current, which increases if pump load has increased.

Accordingly, it is one object of the present invention to provide a novel electro-hydraulic system.

This and other objects of the present invention will become apparent to those skilled in the art, upon reading the following detailed description of a presently preferred embodiment, when considered in conjunction with the associated drawing.

Description of the Drawing

The sole Figure is a schematic block diagram of a presently preferred embodiment of our novel variable-assist electro-hydraulic system.

Detailed Description of a Preferred Embodiment

Referring to the sole Figure, a variable-assist electro-hydraulic system 10 has at least one hydraulic load 11, such as the plurality of loads 11a, 11b, ..., 11n, each connected to a source 12 (such as a pump driven by a shaft 12a) of pressurized hydraulic media, flowing in conduit means 14 interconnecting the pump source 12 and the various loads 11. In many prior art systems, at least one, and probably each, load would have had a separate pressure sensor means 15 (shown in broken line); thus, a #1 load 11a would have had an associated first S1 sensor 15a, a #2 load 11b would have had an associated second S2 sensor 15b, and so forth, until a final #N load with its associated Sn sensor 15n; each sensor would provide a separate signal for feedback to a control means 16, which provides at least one electric power signal (e.g. the three-phase power signals ϕ_a, ϕ_b and ϕ_c, respectively at control means outputs 16a-1, 16a-2 and 16a-3)to a motor means 18 serving to rotate pump shaft 12a at a rotational speed determined in response to the feedback sensor signals.

Control means 16 includes a power switching means 20, such as a full-bridge switch means and the like, providing the respective first, second and third phase signals at its respective 20a, 20b and 20c outputs, responsive to a characteristic of a control signal applied at a control input 20d; an operating potential V++ is applied to input 20e (from means input 16b-1), with respect to a return RTN potential at input 20f terminal 20f (from means input 16b-2). The control signal at input 20d is provided at the control output 22a of a loop control means 22, responsive to the magnitude of a variable reference VAR REF signal at a first input 22b and a sensed current signal provided at a second input 22c by a current sensing means 24; another operating potential V+ is applied to an input 22de (from means input 16b-3), with respect to a return RTN potential at input terminal 22e (from means input 16b-4).

In accordance with one aspect of the present invention, each of the three different phase currents ϕ_a, ϕ_b and ϕ_c is sampled by an associated one of current sensor (transformer) means 26a/26b/26c and the sensor means pairs of leads provide an associated signal at each associated input 24a/24b/24c, to generate the single system-current signal at output 24d, in manner well-known to the art. Thus, signals internal to means 16 are used to obtain the hydraulic-load-responsive motor current signal to be provided at loop control input 22c, without need for any sensor external to means 16.

In accordance with another aspect of the present invention, the other loop control means signal (the VAR REF signal at input 22b) is also generated internal to means 16. The controller 16 includes a variable reference generator means 28 receiving at an input 28a only one selected one of the motor current sensing means 26 outputs (e.g. the output of the phase ϕ_a current sensor 26a) for connection to the input 30a of a current-to-voltage conversion means 30. The resulting motor-current-analog voltage V_m, related to the hydraulic load magnitude, and appearing at the conversion means output 30b, is connected to the input 32a of a rectification means 32. The rectified voltage V_r at means output 32b is coupled to one input 34a of a comparison means 34, receiving a selectable trip signal V_{trip} at another input 34b. The comparator output 34c signal V_c will be at a first level (e.g. a high level) if $V_r < V_{trip}$, and will be at another level (e.g. a low level) if $V_r > V_{trip}$. If the first V_C level is present, as when the pump is providing adequate fluid pressure and flow, then the motor can be controlled to/kept in a low/idle state; if the second V_C level is output, indicative of the motor having to work harder to turn the pump to provide higher fluid pressure and flow, then the motor should be controlled to a more active/faster state.

The comparator output signal is applied to the input 36a of a driver means 36, to generate the VAR REF signal at output 36b/28b, for application to input 22b.

The current-to-voltage converter means 30 has a transformer means 38, with a primary winding 38a of relative few turns N_p, connected between the two input conductors 30a-1 and 30a-2, from the selected motor phase current sensor 26a. The transformer secondary winding 38b, having relatively many turns $N_s >> N_P$ (say, 200:1), has a first end coupled to circuit common (RTN) potential through a first resistance element 40, and another end connected to a first, inverting (-) input 42a of a first operational amplifier 42. The other, non-inverting (+) op-amp input 42b is coupled to common potential through a second resistance element 44. A conversion-factor-setting feedback resistance element 46 is connected between input 42a and op-amp output 42c, which is connected to means output 30b, at which the signal V_m is generated responsive to the ϕ_a motor current. Signal V_m is then applied to means 32 input 32a.

Rectification means 32 includes a first resistance element 48 coupled from input 32a to a first, inverting (-) input 50a of another operational amplifier 50. The other, non-inverting (+) op-amp input 50b is coupled to common potential through a second resistance element 52. A gain-setting feedback resistance element 54 is connected between input 50a and op-amp output 50c, which is connected to the anode of a rectifier diode 56, having its cathode connected to means output 32b, to which are also connected one terminal of each of a load resistance element 58 and filter capacitance element 60, having their other terminals connected to common potential; the signal V_r is generated at output 32b responsive to the peak of the ϕ_a motor current.

Signal V_r is then applied through means 34 input 34a to a first, inverting (-) input 62a of a comparator 62. A trip voltage V_{trip} from input 34b is applied to the other, non-inverting (+) input 62b of the comparator. A resistance element 66 is connected between the operating potential V+ source and the comparator output 62c, which output is also the means output 34c.

The driver means input 36a is coupled through a resistance element 68 to a control (base) device electrode of a switching device (transistor) 70; a common (source) device electrode is connected to common potential and a controlled (collector) device electrode is coupled to output 36b/28b through another resistance element 72; a pair of series-connected resistance elements 74 is connected from operating potential V+ to the output, which is coupled through yet another resistance element 76 to common potential. A ramping/smoothing capacitor 78 is connected in parallel with resistor 76. A maximum-voltage (V_{max})-establishing zener diode 80 is connected at the junction between resistors 74a and 74b.

In operation, system 10 eliminates the need for multiple separate sensors and interfaces by extracting inherent information from the electronic control signals which are always present in the system. Since the pressure in the hydraulic lines 14 is a function of the total loading presented by the hydraulic means 11a-11n, hydraulic pressure is an inherent indication of the load. Generally, when the load increases, there is a corresponding requirement for additional hydraulic flow with a resultant increase in pressure. The converse is true for a decrease in load. The variations in hydraulic pressure relate back to quantities in the electronic control means 16 through the hydraulic pump 12 and electric motor 18, as follows: an increase in hydraulic pressure will create an increase in torque at pump input shaft 12a; the increased load torque applied to electric motor 18 by pump 12 will result in an increased current draw by motor 18. Thus, an inherent indication of load demand is present within the electronic control means 16, by monitoring one or more phase currents by means of a current sensor 26. This inherent, or "load proportional" (control drive derived from load demand), load indicator can be used to control the system so as to reduce fixed power losses and increase system reliability.

In the illustrated reference-following, load-propor-

tional feedback system the hydraulic flow rate is directly proportional to motor speed and by commanding the motor to run at high speeds only when the load demands it, all of the advantages described above can be achieved. The electronic control will command the motor to run at a speed proportional to the variable "VAR REF' voltage. When a change occurs in the load requirement, the control circuitry 28 will change the "VAR REF" voltage level and motor 18 will then be commanded to servo from one speed to another. By correctly selecting the motor speed limits, very low power losses can be achieved with a resultant increase in system reliability. When load demand is low, the motor current level is also low, as will be voltages V_m and V_r, so that comparator output V_C will be at a high level to bias device 70 to a conductive "on" condition. The "VAR REF" voltage will fall to some minimum level set by resistances 72 and 74. Since "VAR REF" is at a minimum, the motor speed, hydraulic flow and hydraulic pressure will also be minimized. If the hydraulic load is increased, the motor current will rise, causing both V_m and V_r to increase; once V_r exceeds V_{trip}, comparator output V_c falls and acts to bias device 70 to the "cut-off" condition. The "VAR REF" voltage will then increase to a maximum set by the zener voltage of diode 80 and the ratio of resistors 76 and 74b. Motor 18 will then servo up to a higher speed (with timing dependent upon capacitor 78), to provide increased hydraulic flow and pressure. Resistors 74b and 76 (and capacitor 78) are selected to limit motor acceleration, in order to minimize excessive motor current.

A typical system 10, for use in an electric vehicle automotive power steering application, reduced fixed power losses by a factor of 10. The controller was powered from a V++ = 180 VDC bus and operated a commutated three-phase brushless DC motor drive. Without load-proportional control, the standby current draw (when no power steering boost is required) was typically 3A DC. With the load-proportional control of our novel system, the standby current draw was reduced to only 0.3A DC. Assuming an 80% system efficiency, the load proportional system dissipated only 10 watts as opposed to 100 watts in the conventional system; the resultant temperature decrease in some electrical and mechanical components can be significant. Since batteries provide the power source in an electric vehicle, power savings and efficiency are extremely important; estimates are up to 9% improvement of overall range of electric vehicles incorporating power steering by the load-proportional power steering system utilizing our invention. With V_{trip} set at 2.0 VDC, a peak motor current of 4.0A was needed to cause a level change at comparator output 34c; this caused device 70 to change VAR REF from 2.0 VDC to 5.0 VDC, commanding motor 18 to increase speed and generating positive feedback because the motor current sharply increases as a result of motor acceleration. A maximum motor speed of about 3000 RPM was attained by setting V_{max} to 5.0 Vdc. When the load is removed from the motor, even at motor speeds of 3000 RPM, device 70 will be biased on. The filter, set up by resistors 74 and capacitor 78, allows proper state changes of comparator output V_c without hysteresis. In the no-load condition, VAR REF tends to stabilize at 2.0 VDC, to implement a motor speed of about 800 RPM.

It will now be seen that the novel control system presented here takes advantage of the inherent relationship between a desired internally-available output parameter (motor torque, related to load) and an internally-available signal (motor current). Use of 'inherently sensing" internally-available signals allows implementation of a variable assist motor control that requires no separate sensing. While many modifications and variations will now become apparent to those skilled in the art, it is our intent to be limited only by the scope of the appending claims, and not by the specific details and instrumentalities discussed with respect to the exemplary embodiment shown herein.

Claims

1. An electro-hydraulic system, comprising:

   a motor having an output speed responsive to an electrical input;
   a pump for pressurizing hydraulic fluid, with a flow responsive to the output speed of said motor;
   at least one hydraulic load receiving pressurized fluid from said pump; and
   means for controlling the speed of said motor responsive to a motor/pump parameter sensed within the controlling means itself.

2. The electro-hydraulic system of claim 1, wherein a reduced load pressure reduces a sensed motor parameter, to reduce pump fluid flow.

3. The electro-hydraulic system of claim 1, wherein said motor has a variable output speed and an output flow of said pump is variably responsive to said variable motor speed.

4. The electro-hydraulic system of claim 3, wherein the motor speed and pump flow characteristics are selected to minimize fixed energy losses with the system.

5. The electro-hydraulic system of claim 1, wherein the sensed parameter is a motor current.

6. The electro-hydraulic system of claim 5, wherein said motor requires a plurality of different motor current phases and said controlling means senses only one phase current as the controlling parameter.

7. The electro-hydraulic system of claim 6, wherein the controlling means includes a current transformer for sensing said one phase current.

8. The electro-hydraulic system of claim 1, wherein said controlling means comprises: means for generating a variable reference voltage responsive to the sensed parameter.

9. The electro-hydraulic system of claim 8, wherein the sensed parameter is a motor current; and further comprising means for converting said motor current into said variable reference voltage.

10. The electro-hydraulic system of claim 9, wherein said converting means comprises: a current transformer for sensing the motor current; current-to-voltage converter means for providing a signal of magnitude responsive to the output of the current transformer; and a comparator for switching between first and second voltage levels responsive to the magnitude of said signal, to generate said variable reference voltage.

11. The electro-hydraulic system of claim 10, further comprising means for obtaining and holding a peak value of the signal for a selected time interval.

12. The electro-hydraulic system of claim 11, further comprising driver means for providing each variable reference level with one of plural preselected voltages.

13. The electro-hydraulic system of claim 11, wherein the comparator compares the signal peak value against a predetermined trip voltage.

14. The electro-hydraulic system of claim 11, wherein the variable reference voltage time-rate-of-change is limited by a capacitive element.

15. The electro-hydraulic system of claim 11, wherein the maximum variable reference voltage is limited by a zener diode.

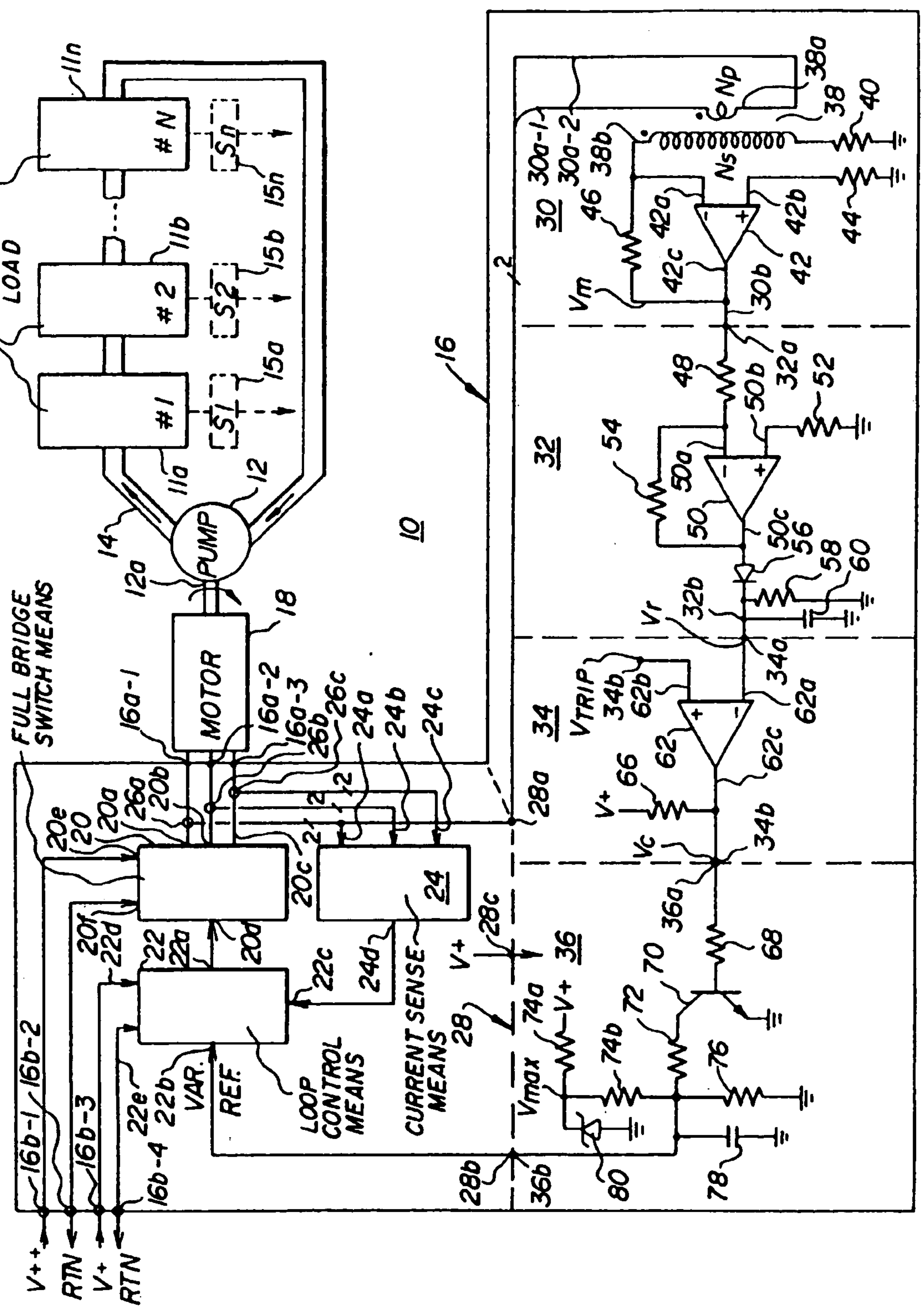
HYDRAULIC LOAD
#1
#2
#N
S1
S2
Sn
PUMP
MOTOR
FULL BRIDGE SWITCH MEANS
LOOP CONTROL MEANS
CURRENT SENSE MEANS
VAR. REF.
V++
RTN
V+
RTN
Vm
Vr
VTRIP
Vc
Vmax
Np
Ns
10
16
18
24
30
32
34
36

FIG. 1